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AGRICULTURAL MEMORANDUM NO 423

An annotated bibliography on the effects of mulching on plant climate, with some comments on consequent yields.

Part II - Effects on temperature

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Part I of this bibliography was issued as Agricultural Memorandum No 392.

2.1 NO SPECIFIC CROP

The effect of the colour of the soil surface has been examined by Aderikhin (1) who found that temperature at the surface and at 20 cm depth was higher in soot-blackened soil than in natural soil or in soil whitened with chalk. Soil temperature was lowered by artificial moistening, particularly in darkened soils but was increased when the orientation of planting rows ran from north to south. Suzuki (4) found that a covering of carbon black increased daytime surface temperature by 5-6°C and the maximum and minimum temperatures at 3 cm depth by 1°C.

Organic mulches

Kristensen (3) reports that a 10 cm straw mulch increased the "mean relative weekly temperature fluctuation" of the air at 5 cm but reduced that of the soil at 5 cm compared with short cut grass and bare soil which had been either left undisturbed or loosened.

Mulching with peat also led to decreased soil temperature variations according to Pflug (21).

Fuss (5) shows that 5 cm soil temperatures were below 0°C at 0800 on only 9 days under a straw mulch but on 56 days in untreated soils.

Webster (11) found that 10 cm soil temperatures were lower at 1200 and 1700 (but higher at 0730) in plots covered with 5 cm sawdust mulch than in unmulched plots receiving 25 tonnes/ha manure disced in every year. After August under irrigated conditions and after October without irrigation, soil temperatures became higher under the mulch where heat loss was slower. Blackening the mulch surface with furnace residue markedly reduced temperature differences between the plots.

Hanks (12) studied the effect of bare soil, straw mulch, gravel painted black or aluminium and also plastic covered ridges and showed that net radiation was highest on the black and least on the Al-painted treatment. Soil temperatures at 1, 4, 16, 64 and 152 cm depth were lowest under straw and highest under plastic. No direct relationship between net radiation and soil temperature was found.

Rauhe and Lehne (9) and Lehne (13) report an 8-year trial in which mulching with straw, potato tops or farmyard manure increased soil temperatures in autumn but decreased them in spring.

FH1

Van Wijk (14) calculates the effect of a mulch on surface temperature, assuming equal sinusoidal irradiation on the mulched and the original soil and takes into account the different distribution of heat between soil and air in the two cases. A 13 cm layer of sand over a peat soil reduced the temperature amplitude to 60% of the value for uncovered peat, which is important for decreasing the risk of frost.

Kohnke (19) gives the results of 5 year records at 2.5, 10 and 25 cm depth in silt loam left bare or mulched with 3.7 tonnes/ha straw. The mulched soil was $\frac{1}{2}$-1°C warmer in winter but $\frac{1}{2}$-1°C cooler in spring and $1\frac{1}{2}$-2°C cooler in summer than bare soil. Daily temperature fluctuations at 2.5 cm depth were greater in bare soil and frequency of freezing was greater. Even though twice as much total heat energy reached 2.5 cm depth in bare soil as under mulch, the net heat energy retained was the same in both.

Greb (24) studied the effects of straw mulch and found that maximum daily soil temperatures were reduced by nearly 1.5°C per 1,120 kg/ha of added straw. A clear plastic canopy over the mulch increased daily maxima at 2.5 cm depths by about 6°C.

Desjardins (31) presents experimental data on the degree and duration of protection against frost offered by a protein based foam and states that the effectiveness of the method depended on the synoptic situation which produced the frost.

Non-Organic mulches

Gliniecki (6) found that black plastic films were the most durable of the polyethylene films tested and that soil temperatures 10 cm beneath the film were higher than in bare soil. Black (15) also reports increased soil temperatures of $1\frac{1}{2}$-4°C under a black polythene film and Qashu (29) shows a similar effect using a black granular mulch both in the field and in the laboratory.

Honma (7) shows that at 12.5 cm depth under black polythene the temperature was 1.4°C higher than in bare soil, and also that the air temperature just above the soil between 0400 and 0600 averaged $\frac{1}{4}$-$\frac{1}{2}$°C higher. Soil surface temperatures under the polythene were lower than bare soil during the day but the temperatures of the air beneath the films averaged 5-17°C warmer.

Clarkson (8) used 122 cm wide film in studies lasting 3 years and found that soil temperatures showed increases of 5°C at 2.5 cm and $\frac{1}{2}$°C at 15 cm under black polythene. These increases were not harmful to plant growth but increases of 11-14°C at the surface of the mulch and 5 cm above it were recorded and such temperatures could cause injury.

Compared with bare soil, Waggoner (10) found that an opaque mulch, especially if of high reflectivity and relatively thick, was warmed more by insolation and emitted more energy upward, decreasing the diurnal amplitude of soil temperature. A transparent mulch, however, transmitted insolation to the soil; the air beneath the mulch and the high emissivity of water on the film retarded the loss of energy and the amplitude and mean value of the soil temperature were increased.

Lyon (16) examined clear, black and reflective polythene and found that at night, soil temperatures under all the mulches were similar to those in bare soil. During daylight, however, temperatures under reflective polythene and in bare soil were similar and both were much lower than those under clear and black polythene.

Pusztai (17) presents graphical data on temperature variations in the profile of soil mixed with white or black powder, covered with white, black or clear plastic

mulch compared with bare soil and in a later paper (22) shows that mulching with plastic foil increased mean temperatures by 6-8°C on clear summer days and by 2-6°C when the soil was covered with dense vegetation.

Collis-George (18) points out that a bitumen mulch gets into close contact with the soil surface and unlike other mulches does not produce an air layer over the soil. This together with the dark colour of the material results in soil temperatures increasing with the thickness of the mulch (up to 4½ litres/sq. metre).

Cohen (23) examined the effects of black and brown rubber in an oil/water emulsion sprayed over the soil and found that the average temperature difference between treated and untreated plots at depths of 5, 10 and 20 cm was 4.5°C for the black cover and 1.8°C for the brown. Treated soils were warmer than control soils at night as well as during the day.

Myhr (26) states that the higher soil temperature found under an asphalt mulch is due to decreased evaporation and increased absorption of radiant energy.

Jordan (28) reports on experiments with bitumen mulching and at a depth of 5 cm found increases ranging from 2°C in England to 8°C in Trinidad. Temperatures under bitumen were higher than those under polythene, sand or pine-needle mulches and in unmulched soil. Mulch bands should be at least 15 cm wide for maximum temperature increments to occur.

Zacharov (32) presents a mathematical analysis of a model for an opaque mulching cover, which allowed calculation of the soil temperature under the cover as a function of meteorological conditions and the thermophysical properties of the film. Mulching with oil products and bituminous paints caused a positive thermal effect, peat and straw a negative effect during daytime.

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2.2 TEMPERATE TREE FRUITS

Organic mulches

Gilbert (1) reports on a 2-year test which shows that frost injury to cherry trees was less on clean cultivated plots than on sod mulch plots. Soczek (6) also reports increased incidence of frost damage to cherry trees with mulches of sawdust, peat and straw compared with clean cultivation. However mulching is claimed to be the best method for protecting the roots of fruit trees from frost damage in winter according to Blasse (8) who also states that frost penetration in the soil was reduced by the sowing of cover crops. Kramer (17) suggests that a mulch of clover grass mowings around apple and pear trees gave a greater risk of spring frost.

Athenstädt (2) considered the depth of freezing in the soil in the central German plain during a period of prolonged frost (minimum temperature -21°C). Soil was frozen to 60-70 cm under clean cultivation, 50-55 cm under a mulch of roofing paper, 40 cm under grass sod, 18 cm under reeds, and only to 13 cm under a mixture of straw and potato haulms. Will (12) found that frost penetration in an experiment in 1956 was only 8-9 cm under a permanent grass mulch but 28 cm under clean cultivated soil.

Rasmussen (3) carried out a 2-year experiment in an orchard of Cox's and presents a great deal of data in charts and tables. The temperature of the topsoil was 2-6°C lower in summer and 2-3°C higher in winter under a straw mulch than under short grass or clean cultivation. At a height of 10 cm above the ground the minimum temperatures during May and June were about 5°C lower over straw with night frosts occurring even in June compared with grass or clean cultivation. At a height of 50 cm the differences between the surfaces were less pronounced. Fuss (4) shows that a mulch of rape straw under bush apple trees reduced the maximum temperature in the top layer of the soil by 10°C compared with uncovered soil and the absolute annual variation was reduced by 21.1°C.

Karnatz (5) recorded injuries to the carpels and stamens of apple spindle bushes in 2 late frost years. These amounted to 40% on cultivated soil and to 70% on soil mulched with leaves. The insulating effect of the layer of leaves was reflected in temperature measurements at various levels above the ground.

Engel (7) compared clean cultivation with a permanent straw mulch and a cover crop of mustard in summer in a 4-year old orchard of apple spindle bushes. Air temperature showed the most extreme values over the straw cover but soil temperature variations were smaller and the mean value lower under the straw. Under mustard, temperature conditions were similar to those of the clean cultivated soil. In a later publication (10) he again reports the lower air temperatures recorded over straw during frost.

A soil cover keeps soil temperatures higher than in bare soil, decreases frost penetration by 10-30 cm and hastens the increase of soil temperature to 8-10°C to 20 cm depth in the spring, according to Van Eimern (9).

The effect of straw mulch in a citrus orchard was studied by Nakagawa (11). At night soil temperatures were higher and by day they were lower under the mulch than in a clean cultivated plot. It is suggested that this is due to the straw absorbing less radiation and having a low heat conductivity value. In a container experiment with apple trees in Israel, Lavee (14) shows that mulching with wood shavings reduced the soil temperature at 5 cm depth by up to 11°C.

Dancer (16) found that soil temperatures were generally lower under a mulch of strawy farmyard manure and also clover-grass swards than under arable treatment. In a 24-hour study under cloudless, windless conditions the diurnal change in soil temperature was least under the mulch and greatest under the arable treatment.

Nyhlén (18) reports that although mulching with straw increased yields compared to those from trees in clean cultivated soil, in several years the flowers on the mulched trees were frost damaged.

Non-Organic mulch

Fibreglass sheets laid on the soil are shown by Page (15) to provide protection comparable to that afforded by 30 cm of snow and appears to be one method of protecting frost-sensitive apple rootstocks from winter damage.

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2.3 TEMPERATE HORTICULTURE AND SOFT FRUIT, VEGETABLES AND FLOWERS

Organic mulches

The use of sawdust as a mulch has been examined by a number of writers. Hansen (8) presents data on the effect of a 5 cm and a 12 cm sawdust cover on soil temperature and on the depth of ice in the soil. Denisen (1) shows that soil temperatures at 2.5 and 7.5 cm depths, measured at 1600, were 4-5°C lower in a sawdust mulched plot than in an unmulched plot. Kragtwijk (3) states that sawdust had little effect on the average soil temperatures although coverings of reeds or shade mats reduced

them. Vaughan (4) says that sawdust mulching "apparently lowers the soil temperature" while Massey (10) shows that soil temperature fluctuations were reduced by a sawdust mulch. Sawdust mulching for container-grown ornamentals was examined by Halfacre (63) who found that air temperatures above the mulched plots were up to 3°C lower than temperatures above the unmulched blocks between 0400 and 0800. Soil temperatures were higher in the mulched containers. Webster (11) lists the results of the effect of a sawdust mulch on soil and air temperatures using a wide variety of individual crops in his experiments.

Straw mulches have been used by Thorsrud (12) who reports that soil temperatures at 5 cm depth were significantly lower under straw both by day and night and that the decrease in daily temperature variation with increasing soil depths was more marked under a straw cover. Honda (49) also found that a straw mulch reduced the average soil temperature, compared with clean cultivation, and Surlekov (54) shows that a mulch of straw at a rate of 8 metric tons per hectare reduced the range of soil temperatures, a result confirmed by Wiebe (74) who found that a mulch of 12½ metric tons per hectare reduced both surface and soil temperatures.

Air temperatures at 5 cm above a 10 cm hay mulch averaged 3°C lower in October and November than those above non-mulched plots according to Creech (16).

Fekete (2) indicates that peat, manure and straw mulches all maintained more even soil temperatures than were found in unmulched plots during a very wet season. Ground corncobs applied as mulches in different amounts to rose bushes are shown by Watson (5) to result in lower and more uniform soil temperatures during the summer months. Müller (14) compared mulching strawberries with leaves and also a mixture of reeds, straw and sawdust and found that both mulches lowered maximum and increased minimum temperatures in the soil.

The use of shredded sugar cane stalks is shown by Hoogendoorn (17) to prevent frost heaving in autumn when used as a mulch on cutting beds. Rauhe (19) shows that from October to May, mulches of straw, potato haulms, and stable manure were effective in that order in moderating soil temperature at a depth of 5 cm and Awan (40) reports that the effect of mulching with hay was to reduce the mid-day soil temperature at 5 cm depth by about 5°C.

Mulching with grass and soya bean residues is shown by Miyasaka (67) to reduce the maximum soil temperature at 5 cm depth from 48°C to 27°C and the diurnal range at the same depth from 32°C to 8°C.

Non-Organic mulches

Emmert (7) reports that black plastic strips (1½ mm thick and 91 cm wide) used as a mulch for early vegetables raised soil temperatures by as much as 5°C. To prevent the soil becoming too hot in midsummer he recommends that aluminium pigmented polythene be used to reflect the light. Peyer (9) also found that strips of polythene film laid between the rows resulted in higher soil temperatures in the morning than occurred in unprotected soil, while Leyvraz (13) states that soil temperatures under a white opaque plastic mulch were lower and those under strips of clear plastic were 3-4°C higher than the temperatures of uncovered soil. Thompson (21) however, used an opaque plastic mulch and found that it increased soil temperatures in cool weather and reduced them in warm weather, while a clear polythene mulch was shown by Cannell (22) to increase day and night soil temperatures on strawberry beds early in the season, and Miller (27) shows that a black plastic mulch reduced soil heaving by frost.

Voth (15) found that soil temperatures under black polythene were very low and does

not recommend the material for strawberries unless weed control is of primary importance.

Temperatures under a brown fungicide-treated paper mulch were about the same as in cultivated soils according to Oebker (18) while Shadbolt (20) found that minimum temperatures were 2 to 4°C higher than air temperature under continuous plastic covers compared with 1-3°C higher under individual caps of paper.

Leyvraz (24) reports on soil temperatures recorded at 15 cm depth in a vineyard under (i) control, (ii) black polythene strips, and (iii) clear polythene strips. Mean temperatures over a week in early summer were: at 0700 - (i) 17.1°C, (ii) 18.2, (iii) 20.2; at 1330 - (i) 20.1, (ii) 21.1, (iii) 25.3 and at 1800 - (i) 23.5, (ii) 23.4 and (iii) 28.8°C.

Mareček (25) found increases in soil temperature under 0.08 mm clear polythene which ranged from 5°C at the surface to 2.8°C at a depth of 50 cm. However, the temperature between the soil surface and the film reached 42.8°C. Vlček (26) meanwhile reports an average increase of 20°C in soil temperatures taken under polythene sheets in a glasshouse.

Shadbolt (29) compared several types of polythene mulch and raised covers. Soil temperatures were generally highest near the centres and lowest near the edges. Perforations in the film had little effect on minimum soil and air temperatures but day temperatures were generally reduced. Soil temperatures under a clear mulch reached 6½°C above those under a black mulch, but minimum soil temperatures under each mulch were similar, being 3-4°C higher than in uncovered soil.

Sondern (30) reports on experiments on the use of black, inflated black and reflecting plastic films as mulches and discusses their influence on soil and air temperatures, while Tarakanov (31) studied the effect of a transparent plastic mulch and found increases in the 5 cm soil temperature of 7-10°C by day and 2-5°C by night. Some increases in air temperature were also found.

Linden (34) used a black polythene mulch on strawberry beds and reports higher minimum and lower maximum soil temperatures than in bare soil and Milner (35) shows that a mulch of an emulsion of petroleum resins also raised soil temperatures. Moore (36) showed an increase in soil temperatures using a black polythene mulch but states that the increase was not sufficient to affect plant growth of vines appreciably.

Takatori (37 & 46) used black and clear polythene bands and petroleum as mulches and noted higher soil temperatures both by day and night than in unmulched soil. Increases by day were less under black polythene than in the others but it conserved more soil heat at night. Austin (39), however, found that soil temperature was little affected under a mulch of 0.04 mm black polythene film.

Black and brown paper and black polythene mulches were compared by Courter (41) who found that soil temperatures under paper were lower, and those under polythene were higher than cultivated soil during the main period of growth of cucumbers. Dhesi (42) used polyethylene covers with black or white tops and also 2.5 cm thick 'Sarkanda' mats and after irrigation of potatoes found the lowest soil temperature to be under the mats, which kept soil temperature constant for 1-4 days after irrigation. Laprade (43), however, shows that soil and air temperatures were higher under plastic than under cheese-cloth when used as a mulch for tobacco seedlings.

Kasahara (50) compared the effects of black (B) fluorocarbon film with green (G), yellow (Y) and transparent (T) vinyl films and white (W) polythene film on soil temperatures at 1 cm depth and found that the mean of maximum and minimum, the

maximum, and the 1000 temperature decreased in the order W-G-Y-T-B while the descending order for the minimum temperature was T-B-Y-G-W. Branzanti (76) also compared the effect of black, grey, clear and green plastic film and showed that they all gave higher soil temperatures than the control throughout the winter with little difference between them. Soil temperature remained below 7°C in December but in January there were at least 30 hours above 7°C under black, grey & green plastic and none under clear plastic or in the control. In February the control had 48 hours above 7°C and the mulched plots 217-290 hours. In March, however, the control and mulched plots had equal totals.

Larpes (51) reports that the use of Encap as a mulch on carrots during a dry summer raised soil temperatures at 5 cm by about 1°C, and Wilson (56) also describes trials of liquid mulching with asphalt or wax preparations which resulted in higher soil temperatures. Zahara (57) notes an increase in soil temperatures especially in cool weather, under a petroleum mulch sprayed as a 10 cm band, and Johnson (65) shows that the application of a petroleum base wax emulsion mulch at 0.3 litres/sq.metre increased soil temperatures at 5 cm by about $\frac{1}{2}$-1°C while Jordan (66) reports increases of 1-2°C in England and 8°C in Trinidad when using bitumen mulches. Sale (72) also notes an increase in soil temperature using a petroleum mulch sprayed in bands over seed rows of vegetables.

Mostert (52) found that soil temperatures under clear or black plastic strips 60 cm wide were 3-5°C higher than those of bare soil, while Downes (61) reports that the soil warming effects of plastic mulches ceased as soon as leaf growth shaded the mulches, but clear polythene transmitted more heat than grey plastic and grey more than black.

Irizarry (82) reports an increase of $\frac{1}{2}$°C at 5-10 cm depth under a black polythene mulch compared with bare soil in Puerto Rico and Caruso (77) presents graphs to show the effect of black plastic mulch on soil temperatures and maximum and minimum air temperature in Sicily, while Voth (80) shows that in California the use of a clear polythene mulch raised soil temperatures by between 2 and 6°C in January compared with unmulched soil and in (81) reports that petroleum mulching in August resulted in very high soil temperatures(26-29°C) and the death of many strawberry plants.

Several writers have directly compared the effects of organic and non-organic mulches. Widmoyer (6) reports on the use of sawdust, ground corncobs and coarse vermiculite mulches and notes less extreme soil temperatures under all the mulches, while Chipman (23) compares black polyethylene with sawdust as a mulch and found that higher soil temperatures were recorded under the plastic. Lemaitre (44) also found that the soil temperature was higher under black polythene than under straw both in the open and under glass.

Schales (45 & 73) indicates that $2\frac{1}{2}$ cm soil temperatures early in the season were increased by $5\frac{1}{2}$-$6\frac{1}{2}$°C under clear plastic and sprayed petroleum mulch, and $1\frac{1}{2}$-3°C by black plastic. White plastic did not affect soil temperatures and straw and peat moss mulch reduced them by $4\frac{1}{2}$-$6\frac{1}{2}$°C.

Brand (47) found that a black plastic mulch was superior to a straw mulch for storing soil warmth during the day and temperatures were 1-$1\frac{1}{2}$°C higher under the plastic and Thorsrud (55) also found that soil temperatures in the rooty area of strawberries were considerably higher under a black plastic mulch than under straw and, later, (84) reports that black plastic foil also increased soil temperature.

Overcash (68 & 69) used mulches of black polythene, pine needles and sawdust for 2 seasons and compared the results with clean cultivation as a control. He reports that soil temperatures at various depths were up to $5\frac{1}{2}$°C higher in polythene-mulched and control plots than in plots under organic mulches.

Bowers (75) compared the use of plastic mulches with large water-filled plastic bags and reports one occasion when the air temperature fell to -4.4°C, the 1.25 cm depth soil temperature fell to 0°C on unmulched plots, to 2.6°C under plastic mulch and to 4.8°C under water-filled bags. Sondern (79) also reports on the use of such bags and states that their use in winter prevents the soil beneath them from warming up as quickly as bare soil. They offer some frost protection since they retain heat accumulated during the day.

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2.4 FORESTRY

Posey (1) found that soil temperatures were lower under a sawdust mulch than in unmulched beds but Farnsworth (2) effectively controlled frost heaving during winter with a 3.2 cm deep sawdust mulch applied the previous autumn to conifer transplant beds, while Mullin (16) shows that a sawdust mulch gave better prevention of frost heaving in seedbeds than gravel, vermiculite or straw. Woods (3) suggests that a 5 cm mulch of pine needles around seedlings acted as a heat trap with a surface temperature within the mulch reaching 71°C compared with a bare sand surface temperature of 62°C, while Dumitrescu (5) applied a 20 cm layer of straw before the snow had completely melted over one year seedlings and found that it delayed snow melt and protected the seedlings from late frosts.

Surface temperatures during a hot dry summer are reported by Salisbury (6). In full sunlight heat damage to seedlings was greater on a plot mulched with dark sawdust and temperatures at the surface of the mulch were 8-11°C higher than at the surface of a soil cover. Simon (7) shows that temperature extremes during the growing season were greater in the soil beneath and in the air above mulches of shavings and Koshi (8) recorded temperatures during August of 48°C at 15 cm above the ground, 63°C at the surface of a pine needle mulch and 53°C at the bare soil surface.

Meiman (9) studied different combinations of sandstone fragments used as a soil cover in a greenhouse and found that they had no effect on soil temperature. However Mustafaev (15) shows that a 2 layered mulch of flat stones improved the temperature.

Lavee (13) found that a 10 cm layer of wood shavings decreased soil temperature by as much as 11°C at 5 cm depth while Hoffman (14) successfully substituted a petroleum mulch (Encap) for pine needles which effectively warmed the soil when growing Eucalypts.

Stephens (17 & 18) regulated soil temperature by a choice of either green or black polythene film or salt-marsh hay.

Soil temperatures at depths of 7.5 and 15 cm in peach plots were compared by Morris (19) under grass, bare soil, cultivated soil, and under a straw mulch. He found that those under straw were much lower and diurnal variation was much less than with the other treatments. With all treatments the maximum was higher and the minimum was lower at 7.5 cm than at 15 cm. Solbraa (20) confirmed that mulching with bark decreased the temperature range and the mean soil temperature, while Fraser (21) reports that mulching seed spots with an algin gel reduced maximum soil temperatures compared with untreated plots. A petroleum mulch, however, is shown to increase maximum soil temperatures.

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2.5 GRASSES AND CEREALS

Organic mulches

Hopkins (1) reports on the effects of vegetative material used as a mulch at rates varying from 1 to 25 tonnes per hectare, while Potter (3) discusses the effect of a wheat mulch and grass sod on maximum and minimum soil temperatures, heat penetration, frost duration and thawing at depths ranging from 2.5 cm to 1.8 m at 5 different sites. He notes that the greatest lag of heat penetration and loss was observed under a maize crop where temperature changes occurred 1½-2 months later than those on ploughed fields.

Differences in soil temperature of as much as 5½°C early in the season between soil mulched with corn stalk and bare soil were found by Parker (4) and in a later paper (5) he considers nitrification in relation to the effect of a mulch on soil temperature, while Willis (7) carried out greenhouse and field experiments to determine the effect of mulching on the growth of corn related to soil temperature.

White (9) summarizes the results of 3-year field experiments on maize with pine sawdust ploughed in at rates varying from 7 to 47 tonnes/hectare or given as 50 tonnes/hectare mulch (2.5-4 cm). The sawdust incorporated into the soil had no beneficial effects on plant growth and the higher yields on the mulched plots were associated with a decrease in soil temperature. Van Wijk (10) however, found that lower temperatures under a mulch of oat straw, either left on the surface or ploughed in, tended to decrease the early growth of maize. Application of the heat-flow theory in predicting soil temperatures in the entire root zone from measurements at 10 cm depth, and calculation of the effect of mulching on soil temperature are discussed.

In the report on stubble mulching (11) lower yields of maize are thought to be due to the mulch affecting soil temperature. Burrows (13) and (19) confirms that maize yields are usually lower under mulch tillage and concludes that this is attributable to the relatively lower soil temperatures early in the season under the mulch, the quantities of which varied from 2.5 to 20 tonnes/hectare. Each tonne of mulch, up to 10 tonnes/hectare decreased the average 10 cm soil temperature by 0.4°C in May and June. Parker (20) also found that crop residue mulches used on corn, lowered soil temperature, as did Moody (22) who mulched maize with 7.5 tonnes of wheat straw/hectare both ploughed in and left on top and who found that mulching reduced the soil temperature throughout the growing season.

Anderson (24) found that each ½ tonne/hectare increment of straw mulch up to 5½ tonnes/hectare depressed the late morning soil temperature at 10-20 cm by an average of 0.33°C during early growth, 0.36°C by mid-June and 0.41°C by mid-July when the wheat crop completely shaded the soil surface.

Van Doren (37) considers the effect of mulching on soil temperatures and early growth of maize, while Brengle (38) reports that greenhouse cultures of wheat, grown in pots, in controlled temperature waterbaths had lower soil temperatures with a

straw mulch (5 tonnes/hectare) than without surface residue in the earlier stages of growth.

Non-Organic mulches

Clarkson (14) used a black plastic mulch 0.04 mm thick and 120 cm wide and found that the maximum and minimum soil temperatures from 2.5 to 7.5 cm were higher under the mulch, the minimum surface temperatures were lower, and temperatures at the surface of the mulch and 5 cm above were higher where the plastic sheets were applied, while Fritschen (15) measured the 5 and 10 cm soil temperatures under a black plastic cover and found that they were higher and subject to less fluctuation than those in uncovered soil, especially at night. Diurnal ranges of soil temperatures were less under the mulch and were non-linearly correlated with net radiation. Daily maximum soil temperatures occurred about 2 hours later in covered soil and minimum temperatures at about the same time.

Bement (16) compared different coverages of quick- and slow-setting asphalt emulsion over grass seed and found that soil temperatures were higher down to 30 cm under the quick-setting emulsion, while Adams (18 & 34) shows that clear plastic covers and petroleum mulch increased the 7.5 cm soil temperature by up to 5.5°C during the early season when used with sorghum and maize.

Free (29) includes information on soil temperature throughout the growing season in his report on a 3-year study of the use of translucent plastic sheeting used as a mulch for maize and Dinkel (32) reports on the use of 90 and 120 cm wide clear plastic used as a mulch for sweet corn grown in Alaska. Soil temperatures were increased sufficiently for marketable ears to be produced.

Army (12) compared sheets of polyethylene plastic with roofing paper and aluminium foil and found that soil surface temperatures in the afternoon were lower under paper and foil than on bare ground, but much higher under the clear plastic in hot weather, and Miller (21) shows that soil temperatures were higher under perforated and non-perforated transparent polythene and lower under non-perforated black polythene than in uncovered soil.

Pusztai (23) reports that soil temperatures 2 to 10 cm depth under plastic foil 0.08-0.1 mm thick compared with unmulched plots were lower under white-coloured material and higher under black and transparent material, while Read (25) shows that soil temperatures under white styrofoam and brown-grey vermiculite mulches were about the same and were < 0.6°C lower than under bare soil in glasshouse experiments with self-irrigated pots. Zakharov (26) however, found that transparent film between the rows of maize increased the soil temperature in the rooting zone but mulching with black film usually decreased it. The temperature of the air near the soil was highest under black film.

Harris (30) used 90 cm wide black polythene and 30, 60, 90 and 120 cm wide clear polythene mulches and found that the clear mulches increased soil temperature by up to 8°C over the control. The black mulches increased minimum but reduced maximum soil temperatures in spring and increased both maximum and minimum soil temperatures during the summer, while Hopen (31) shows greater soil temperature increases under a transparent mulch than under a black mulch.

Willis (6) reports on field and glasshouse experiments using straw and polythene mulches. The presence of a mulch decreased thermal conductivity compared with non-mulched samples and dark material (eg straw sprayed with carbon black) produced higher soil temperatures. Adams (27) however, studied the effect of straw, gravel and DDAC-treated soil as mulches and shows that soil surface and mulch-soil interface

temperatures on fallow plots descended in the order: bare soil > 2.5 cm gravel > 5 cm gravel > straw. Daily soil temperatures at 1330, at 7.5 cm depth varied from 32-35°C under bare soil to 27°C under straw from early June to mid-August.

Brock (28) reports that golf greens were re-seeded successfully during winter and early spring using a cover of clear polythene. Soil temperatures were higher and they fluctuated less than those of unprotected soil. Mulching with straw, however, proved unsuitable.

Miller (36) compared bare soil, asphalt sprayed on the soil after sowing, glasshouse panes placed between the rows and water filled bags placed between the rows and found that soil temperatures in early spring were lower in bare soil than with the other treatments. Other experiments with water filled bags 10 cm thick (33) showed reductions in maximum and increases in minimum temperature at a depth of 1.25 cm but increases in both extremes at 10 cm depth. Bowers (35) also used 10 cm water filled bags between rows of sweet corn and found they acted as a heat source during the night and greatly reduced diurnal temperature fluctuations at 1 and 10 cm depths.

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2.6 TROPICAL AND SUB-TROPICAL CROPS

Organic mulches

Gogolishvili (1) compared the effect of several mulches in a citrus orchard and found that bracken and peat decreased soil temperature by up to 2.0°C while tarred paper increased soil temperature by 1.2°C. Havord (2), Smith (3) and Taylor (6) all noted reduced soil temperature fluctuations under different types of mulches (grass, wood shavings etc) with various crops (cacao, coffee, citrus), while Medcalf (5 & 7) reports lowered soil temperatures in a coffee plantation under a grass mulch.

The effects of mulching with straw in a vineyard and a tobacco field were studied by Onchev (11 & 17) who found that during hot days soil temperatures were 2-18°C lower under the mulch than in bare soil, but in winter the soil temperature was higher under the mulch. On clear calm days air temperatures 35-40 cm above the mulch were 0.1 to 1.6°C higher in August and September than over unmulched plots, whereas at night they were 0.2 to 0.6°C lower.

The diurnal temperature range was smaller in the soil and greater in the air (up to 170 cm) with a grass mulch in an orange grove than with the soil kept clean with herbicides, according to Franco (12). Paes de Camargo (15) using a straw mulch in a citrus orchard reports similarly.

Temperature data for 79 weeks in a cacao estate are presented by Hardy (13) which shows that the daily soil temperature fluctuations were 0.97°C under soil, kept bare and free from litter; 0.42°C under soil left untouched with litter accumulating; 0.36°C under a bagasse mulch and 5.1°C under a grass surface.

Vardzelašvili (19) measured soil temperatures at 5, 10, 15 and 20 cm in clean cultivated soil, under grass and under mulched plots of mandarins. In summer the highest monthly mean temperature was under clean cultivation and lowest under the mulch. In winter the monthly mean temperatures under the mulch were 1.3 to 1.5°C higher than that under clean cultivation which was characterised by greater diurnal and seasonal temperature fluctuations.

The effects of a trash mulch on temperatures were studied by Beater (20), at the surface and at 2.5, 10 and 23 cm depths at 9 sites. At the soil surface the mulch lowered the maximum temperature very considerably and raised the minimum such that the average temperature was reduced by 7.6°C. These effects diminished with depth, but even at 23 cm the average temperature was lowered by 2.6°C. There was only slight variation between northern and southern extremities in the region of the sugar belt of Natal, and greater variations were found over small areas depending mainly on aspect.

Archibald (29) considered temperature measurements at 2.5, 15, 30 and 60 cm inches under mulch, sod and bare soil in a peach orchard. The moderating effect on temperature variations by the mulch was influenced by soil type. In a prolonged low-temperature period with no snow cover the 2.5 cm temperature in the mulched plots was 6.7°C higher, enough to ensure root survival. Thompson (33), however, found that temperature differences between mulched and bare soils depended on season, time of day, depth and also on the density of crop canopy, while Shyu (41) reports that the mean soil temperature beneath a straw mulch on a tea plantation was slightly higher than in bare soil.

Non-Organic mulches

Higher soil temperatures were reported by Lu (4) using a 7.5 cm mulch of coarse sand and gravel. Black plastic sheets were used by Coit (8) with newly planted avocado trees, by Smith (9), Chouteau (10) and Smith (31) with tobacco and all reported an increase in soil temperatures. Castello (39) reports greater protection against frost for tobacco with plastic sheets than with cotton sheets.

Clear and black vinyl film were shown by Goodall (23) to raise soil temperatures by 1.7 to 4.4°C while Jazykov (24) used a paper mulch 15 cm wide with cotton seed and found soil temperatures were up to 1.6°C higher than in the control. Devočkin (22) also found temperature increases using paper bands with a cotton crop. Plastic mulches were compared by Panje (27) on a sugar cane crop and he showed that the temperature of the top soil was raised 2-4°C by translucent film and 0-1.5°C by black film.

A petroleum mulch was used by Phillips (28) at the rate of 0.7 litres/sq.metre in a 20 cm wide strip over cotton rows spaced 102 cm apart, and he found that maximum soil temperatures were increased by the mulch, while Ranney (37) compared different rates of application of petroleum resin mulch on a cotton crop and found that the soil temperatures of the mulched plots were 1-3°C higher than those of the control and the maximum effect occurred with an application of 280 litres/hectare in 15 cm wide bands. Gerard (35) used Encap (a black petroleum mulch) with and without a white coloured reflective coating and found that both significantly increased soil temperatures. However certain reflective coatings lowered soil temperatures at planting depth to below 43°C and provided a favourable environment for the germination of peppers.

Bennett (30) found that under a black plastic sheet 1.5 mm thick the early season soil temperatures ranged from 5°C above to 14°C below those of unmulched soil, but the differences were greatly reduced when the crop of cotton developed a complete

ground cover. Mulching with black paper or plastic on pineapples was found by Ekern (34) to increase the average soil temperature by 1.6°C during the winter, while the use of a white expanded-polystyrene-board mulch on the surface of a paddy field was shown by Murata (36) to increase the reflection of radiation at the mulch surface and to decrease the daily maximum soil temperature.

Engle (16) reports a three-year trial of different mulches with tobacco and shows that the daily temperature range was greatest under a paper mulch and least under a straw mulch. In no case was mulching found to be economic. Blore (26), however, compared a petroleum mulch sprayed on to the soil with a grass mulch and found that soil temperatures under the petroleum mulch were comparable with those on bare soil but grass mulches restricted the daily temperature rise by about 5°C.

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